REPORT

ON THE

PRESENT STATE OF OUR KNOWLEDGE RESPECTING THE GENERAL CIRCULATION OF THE ATMOSPHERE.

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BY

L. TEISSERENC DE BORT.

Météorologiste au Bureau Central Météorologique de France, and Sécrétaire Général de la Société Météorologique.

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Distribution of Barometric Pressure.

The general circulation of the atmosphere is governed by the distribution of barometric pressure. It is therefore necessary, in the first place, to make that our study.

If we collect the observations made during a long period, at a great many places over the globe, so as to ascertain the mean pressure at each of them, either for a year, or for various individual months, we see, as Maury has shown, that the barometric pressure varies with the latitude in an analagous manner in both the northern and the southern hemispheres; so that the distribution, on the whole, is characterized by the following features :—

1. A zone of low pressure near the equator.
2. Two zones of high pressure about 35° north and south.
3. Two zones of low pressure about 55° north and south.
4. Starting from these zones, the pressure increases slightly towards the poles.

When studying the distribution of the pressure in the different months, we see that these zones do not remain stationary, but move according to the declination of the sun.

The following table, based on the maps of the mean isobars, indicates the principal phases of these displacements.

Mean Barometric Pressure in Various Latitudes, Corrected for Variations of Gravity.

Latitude.	January.	March.	July.	October.
	Mm.	Mm.	Mm.	Mm.
60 N.	759·9	760·3	758·3	758·3
55	761·8	759·2	758·6	758·9
50	762·4	760·9	759·2	760·8
45	763·4	761·9	760·0	762·5
40	764·5	762·9	760·4	763·7
35	765·6	763·3	760·1	763·9
30	765·3	762·7	759·6	762·6
25	763·8	761·9	758·6	760·9
20	761·5	760·6	757·9	759·7
15	759·5	759·3	757·2	758·6
10	758·4	758·6	757·3	757·8
5	757·9	758·0	757·9	758·0
0	757·7	757·2	758·6	758·4
5 S.	757·6	757·6	759·6	759·0
10	758·3	757·8	760·8	760·1
15	758·4	758·2	762·2	761·4
20	759·0	759·6	763·3	762·0
25	759·7	760·6	764·8	763·6
30	760·0	762·0	764·8	764·0
35	761·2	762·6	763·6	763·1
40	761·9	760·7	761·1	760·8
45	757·1	758·5	757·9	758·0
50	751·0	755·3	753·1	753·9

We here give the mean pressures for the North Polar regions, according to the isobaric maps for January and July, published by Dr. Hann, in *Berghaus's Physical Atlas:*

	55°	60°	65°	70°	75°	80°	85°
	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.
January	761·5	760·9	762·0	760·0	758·3	757·7	758·5
July	758·4	757·5	757·5	757·5	758·0	758·8	759·3

On the other hand, if we consider the variations of pressure along parallels of latitude, we shall see that the pressure is not uniform, but presents maxima and minima.

The study of isobaric maps shows us that there is a general tendency for the pressure to distribute itself in zones; a tendency which is intensified by the averages of the barometer on the various parallels: but that this tendency is counteracted by causes which make the pressure, even on one zone, vary according to the meridian. This variation is, in the northern hemisphere, even more marked than the variation with latitude; and we find, on one parallel, pressures which differ by 34 mm., although the difference, according to latitude when following one meridian, does not exceed 20 mm.

From the superposition of these variations with latitude and with longitude, result the formation of areas of high and low pressures. These areas, which have a certain permanence in a given season, constitute that which I have called "*the great centres of atmospheric action.*"

Their existence is related to the position of the great centres of action of the globe, regions which, either by their physical properties, or by their orographic character, initiate the great centres of atmospheric action; so called because they govern the circulation of the winds all round them; and their displacement over the surface of the globe, and their variations of intensity are the immediate cause of most of the different characters of atmospheric circulation in diverse seasons.

The maps of mean isobars for January and July, which we have drawn, and copies of which we have given (see Maps Nos. 1, 2), will, better than any description, enable anyone to realize the distribution of pressure in winter and in summer. They show very clearly the influence of the continents, which, being warmed in summer, lead to the formation of low pressure areas producing the monsoons, as Dove showed many years since.

When we study the monthly maps of barometric pressure, we see that in the intermediate seasons, March and October, the isobars approach to parallelism; and that the general circulation is very nearly that which was described by Maury; that is to say, the theoretical circulation. It is, in fact, in spring, and even more so in autumn, that the distribution of temperature is in each hemisphere the most regular, and the most symmetrical with regard to the equator. Thus the disturbing influence, which results from anomalies in the distribution of temperature, is reduced to a minimum.

Distribution of Barometric Pressure in the Upper Strata of the Atmosphere.

The study of the distribution of the lower isobars is not sufficient to define what ought to be the circulation in the whole mass of the atmosphere. It is therefore very interesting to ascertain what are the natures of the isobars at various heights. With this object we have drawn Maps, Nos. 3, 4, 5, 6, representing the isobars at the height of the Puy de Dôme, 1,467 metres (4,813

feet), of the Pic du Midi 2,859 metres (9,186 feet), and of 4,000 metres (13,000 feet), approximately the height of Pike's Peak.

These Maps are drawn, starting with the temperature and pressure at low level stations, and, calculating by Laplace's formula, the value of the pressures above the various points, in the season in question.

The numbers thus found harmonize in a satisfactory manner with the values observed directly at the mountain observatories already mentioned.

It will be noticed that on these Maps many of the irregularities of the surface isobars diminish in proportion with elevation; so that there is a tendency at a certain height to have rectilinear isobars parallel with the equator. This equalization of the pressures depends upon the fact that the diminution of pressure is most rapid where the air is most dense; that is to say, precisely, in the districts of maximum pressure, which are also very often districts of low temperature. Thus we see that, at the height of 4,000 metres, the high pressures of Siberia and of North America are rapidly effaced.

From the same cause, the maxima of relative pressure, which are found on certain parts of the equator, disappear little by little, and the greater pressures approach the equator, and at a level of 4,000 metres (13,000 feet) reach approximately 15° N. and S. Starting from this height, and from this district, the pressure decreases very regularly in each hemisphere towards the poles.

Circulation of the Winds.

The distribution of the winds naturally results from the distribution of pressure. Theoretically it ought to be formed in zones, and Maury's scheme indicates well what it would be if the distribution of temperature (involving that of barometric pressure) were regular.

In consequence of the thermic anomalies, the centres of action which are thereby created destroy the regularity of the winds, and cause the production of the monsoons, which play so important a part in the lower circulation.

The very valuable works of Commandant Brault, "On the Winds Over the Oceans," have defined in a very useful way the laws of the winds over the oceans. If we combine these documents with those collected by Coffin, as to the directions of the winds over the continents, and determine for each point the prevailing winds, we may represent them by a series of arrows which, combined, give a very exact representation of the average circulation in the lower atmosphere.

It is thus that we have prepared and drawn the maps Nos. 7, 8, which represent the prevailing winds of January and July.

These maps, like those of the isobars, show the very important influence of the continents in causing the directions of the wind; and they bring prominently forward the fact, pointed out by Brault, that the winds are deflected from their normal direction towards the hot regions.

Moreover, M. Woiekoff has shown that the *régime* of the monsoons, far from being confined to the tropics, extends far to the north, and prevails over many coasts to such an extent that there are few countries where it may not be traced. The example which we have given in our "*Etude sur la Péninsule Ibérique*"* is very striking, and indicates that, when the geographic circumstances are favourable, we may have very well-marked monsoons in a country far outside the tropics.

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* *Annales du Bureau Central Météorologique, tome* iv., 1882.

Circulation of the Upper Winds.

The circulation of the upper winds was shown long ago by Maury; and if the crossings of the winds, which he suggests, have not been confirmed by observations, the general course of the winds from 25° to 30°, anti-trades, and the general westerly winds which he has indicated have been verified in many cases by the observation of the transference of volcanic dust and especially by the study of the movements of the upper clouds.

Mons. H. Hildebrandsson's maps of the motions of cirrus have further proved the course of the upper winds, and I cannot do better than refer to these maps, first presented in 1889 to the *Congrès Météorologique de Paris*, and subsequently published in various works.

I will call attention to a remark made by the Reverend Father Deschevrens who was astonished that the cirri during the winter went from Asia towards the Pacific, although high pressures prevail over Asia, and one would have expected, according to the rules found for Europe by M. Hildebrandsson, that the cirri ought to follow currents going to feed the upper parts of high pressure areas in Asia.

The study of the map of the mean isobars for January enables us to understand why the cirri diverge from Asia towards the East; in fact, the very pronounced barometric maximum which prevails in the lower regions has disappeared at 4,000 metres, and the general régime of isobars sloping towards the pole has taken its place. Therefore, the winds ought to blow from the West, which is precisely what they do. Moreover, the observations at mountain stations, *e.g.*, Pike's Peak, Sonnblick, Säntis, and even Ben Nevis, show that E winds become rarer with elevation, and as we penetrate the stratum which is the prolongation of the anti-trade, as Dr. Hann has justly remarked, these Easterly winds in middle latitudes are confined to the lower strata.

The eruption of Krakatoa furnished an extremely interesting verification of the retardation of the upper winds with reference to the daily motion in the equatorial regions. The retardation towards the West is about 30 metres the second. These winds, which move almost circularly around the globe, owe this motion to the velocity acquired. It is a striking example of winds of which the principal motion is produced without any gradient. We will examine, further on, an apparent anomaly in the circulation of the upper winds which occurs in summer over Asia. The study of the conditions of the general circulation gives, moreover, a very good account of this anomaly.

THEORY OF THE CIRCULATION OF THE ATMOSPHERE.

Having surveyed the circulation of the atmosphere, as shown by maps representing the present state of our knowledge, it is interesting to try to indicate the causes of that general circulation.

Everyone now agrees that the primary cause is the difference between the temperature at the equator and at the poles. Moreover, the effect of the heating of the continents has been shown by Dove to be the cause of some of the great movements. These are much more wide-spread than has been imagined, as Woeikoff has shown, and as was demonstrated in my *Etude sur la Péninsule Ibérique.*

But the distribution of pressure was only partially explained until Ferrel showed that the decrease of pressure towards the poles was the result of the relative movements of the air with respect to the globe. He has thus explained the belts of maximum pressure which surround the globe about 30° N. and S., but this explanation is insufficient, for it is founded (in order to fix the latitude of the maxima) on the principle of the conservation of areas and on the necessity of not altering the velocity of the earth's rotation, which in reality cannot be invoked.

The taking into account of the effects of the motion with relation to the globe is so important, that Ferrel may be regarded as the author of the theory of the circulation now adopted, with some modifications. The authors of the theories which seem most opposed to it, like those of Siemens, are compelled to borrow much from Ferrel, because the general distribution of pressure is inexplicable if centrifugal effects are ignored. M. Overbeck, by taking into consideration also the relative movement, has succeeded in determining trajectories of the winds, which agree well with observations, and with the theoretical directions previously given by Ferrel.

It is more than fifteen years since I commenced my researches into the general circulation, endeavouring especially to define exactly the mutual influences of the distribution of pressure, temperature, and wind; since then I have studied the works of Ferrel, so that the theory of the general circulation which I submit and which has been the subject of my memoir, "*Etude sur la Synthèse de la Répartition des Pressions à la Surface du Globe*" results from my own researches on the effect of temperature, combined with those of relative movement pointed out by Ferrel. But though one necessarily finds in my theory most of the general ideas expressed by Ferrel, whose works I took as my point of departure, I differ with him on the following points:—

"Employment of the principle of the conservation of areas," which I have not regarded as applicable to the general circulation as it actually exists.

"Theory of the belts of maximum pressure N. and S. of the Equator," which is very different from that of Ferrel.

I have, moreover, added an "explanation of the low pressure zone in Latitude 55° and of the Polar Maximum."

Finally, I have introduced the influence of the "*Inégalité de Température suivant les méridiens*," deriving from my works on the Isanomals (which go back to 1879) an influence scarcely considered by Ferrel.

In my "*Synthèse des Pressions*" I have endeavoured to define, and to measure, the various forces in action, in order to be able to reconstruct by theory the isobars indicated by actual observation. I think, then, that it is noteworthy that the theory which I propose (and which much resembles that of Ferrel) is now the most nearly complete which exists, since, among the points which it explains, it leads to synthetic verifications which, as far as I know, have not yet been made by any one.

I cannot set out here, for want of space, the various theories which have been recently suggested to explain the general circulation of the Atmosphere—theories generally incomplete and uncorroborated by observations. Most of them borrow their essential features from Ferrel.

Influence of the Distribution of Temperature according to Longitude.

For fifteen years I have endeavoured to separate the influence of the distribution of temperature upon the general circulation, by adopting the following line of thought. Having observed the well-known apparent relation of certain barometric maxima, of the small low temperature areas, as well as those of certain barometric minima with high temperature areas, I have tried to ascertain whether that is a general phenomenon; and, when drawing the thermic isanomals (1879), and comparing them with Woeikoff's isobars, I was led to frame the following law:—

(1) When a region, of a certain extent, shows an excess of temperature, either absolute, or relative to the temperature of other points in the same latitude, there is a tendency to the formation of a minimum in that region, and almost precise coincidence between the

barometric minimum and the maximum of temperature, and moreover there is a certain proportionality between them. This tendency is shown either by the existence of a closed minimum, or by an inflexion of the isobars.

(2) Barometric maxima areas, whence the air flows out, have a tendency to form in the neighbourhood of regions where the temperature is low, either absolutely, or relatively to their latitude*—(*Comptes Rendus de l'Académie des Sciences*, Paris, Nov., 1879).

(3) When a region has a mean temperature higher than that of adjacent regions on the same meridian, the pressure in it is less than that in the adjacent regions; this relation holds, up to a distance of 60°.

On the whole, then, we find that the distribution of pressure is closely related to that of temperature; and if one studies the variation of pressure along parallels of Latitude only, it will be found to be almost perfectly explained by the thermic anomalies.

General de Tillo has recently shown that for any one place there is a very marked proportion between the amplitude of the monthly mean pressure in the course of the year and that of the corresponding mean temperatures.

Therefore I have tried whether it is not possible to explain satisfactorily the anomalies in the distribution of the isobars, resulting from the direct effect of temperature, by eliminating that influence of the variation of pressure with latitude which depends on more general causes. With that object I have determined the mean variations of pressure with latitude in each hemisphere; possessing thus for any given month of the year the mean barometric height on each parallel, I have sought how this value ought to be modified as a function of the temperature in order to make it harmonize with the observed pressure.

Our previous researches have shown that in proportion as we ascend in the atmosphere the irregularities in the distribution of the isobars decrease; so that at about 13,000 feet these lines are almost parallel. It appears, then, probable that at a greater height the parallelism is almost absolute.

Starting from a plane situated at 16,000 feet, for example, where the pressure may be supposed to have no other sensible variations than those due to latitude, the effect of the difference of density at various points in the column of air which extends from this plane to the earth's surface, ought to suffice for determining the inflections of the lower isobars. Placing oneself in a plane at 5000 metres (16,000 feet), and adding to the mean pressure corresponding to the latitude, at each point the weight of the column of air of a variable density, which extends from this plane to the surface, we obtain a series of values closely approaching those which are observed. It is this which may be seen on maps 9 and 10 of the isobars of January and July which have been thus calculated.

Notwithstanding the evident relations which exist between these maps and those which result from direct observation, it will be seen that the computed pressures are much too great, and rather too much heaped up towards the north over Asia during the winter; that the barometric minimum over the North Atlantic is exaggerated; lastly, that over North America there is a maximum of pressure which does not really exist. These various inexactitudes appear to depend on two causes, one the density of the column of air from the surface up to 16,000 feet not having been correctly computed, because, for want of precise information we are obliged to assume uniform decrease of temperature.

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*I may be permitted to remark that certain authors have wrongly attached the name of M. Wild for mine with reference to the relations between isanomals and isobars. My works upon this subject preceded those of M. Wild by a whole year. Moreover I have studied the question with reference to all parts of the globe, and not merely over Europe and Asia. The laws thus deduced are general, while the relation deduced by M. Wild is so formulated that the relative position of the centre of the anomaly of pressure, with reference to the thermal anomaly, is defined only for the northern hemisphere, and would have to be modified to render it applicable to the southern.

Since the publication of my maps, recent works, and especially those of Dr. Hann, having shown that the decrease of temperature is more rapid in barometric depressions than in zones of high pressure in our latitudes, we must infer that, in departing from points where the temperatures are equal, as soon as one rises sufficiently, the isotherms are depressed over the regions of low pressure and advance towards the pole over high pressure zones.

We must add to this the certain fact, which has been verified at all the mountain stations and by the Eiffel Tower observations discussed by M. Angot, that there are frequent inversions of temperature during the cold season in the high pressure zones in our latitudes; so that we may consider inversion of temperature in the lower strata to be almost the normal condition in areas of high pressure in winter.

We see, then, that the temperature adopted as the mean for calculating the density of the air over various regions is certainly too low in high pressure zones, and too high over low pressure areas. Whence it results that we find by calculation, pressures too high in the cold regions, and too low in regions of barometric minima like the North Atlantic.

But to this cause must be added another, of which we have taken account in our works; it is that, firstly, where the temperature is already low in the upper regions of the atmosphere, the slope of the surfaces of equal pressure from the equator towards the poles ought to be greater than in the direction of the points where the temperatures are high; secondly, the afflux of air which results from it is more rapid, and the gradient (resistant) due to the centrifugal force is consequently greater, so that the slope of the isobaric surfaces tends to keep itself greater.

In order to obtain accurate results in the computation of pressures, rigorously free from the effect of temperature, it is necessary to know the law of decrease of temperature with height, in order to determine, firstly, the precise form of the upper isobars; secondly, the precise density and the weight of the air between these isobars and the surface.

However it may be, the comparison of the observed, and of the computed, isobars (see Maps 1, 2, 9 and 10), shows a great similarity between them, with the exceptions to which attention has already been directed, and proves the direct effect of the irregular distribution of temperature in modifying the theoretical circulation, and determining the variations of pressure with longitude.

VARIATION OF PRESSURE WITH LATITUDE.

Effect of the Difference of Temperature between the Equator and the Poles, and of the Relative Motions.

The variations of the pressure with longitude having been explained, we have wished to go further, and have endeavoured to determine by calculation (instead of having recourse to observations) the form of the mean upper isobars; that is to say, laws of variations of pressure with latitude. For this purpose it is indispensible to have recourse to the works of Ferrel, who first gave the explanation of the cause of the depression of the isobars towards the two poles, which results from the consideration of the effects of the relative movements, and from the equations of continuity of motion which he has introduced into meteorology.

First hypothesis of the earth immovable on its axis. If the earth did not turn on its axis, the distribution of the pressure according to latitude would be very different from what it is. Under the influence of the difference of temperature between the equator and the poles, the surface of equal pressure would be on a slope towards the poles. But this slope differs from that which would exist upon a globe rotating on its axis. If we suppose that the earth is uniformly covered with air

and that we produce a difference of temperature between the equator and the poles, the slope of the upper isobars, which would originally be established, would be given by calculating the contraction that the atmosphere would undergo towards the poles as a result of the decrease of temperature. But under the influence of this slope, the air, beginning to move towards the poles, will tend to restore the equilibrium and to fill up the relative vacuum formed over the poles. It will produce thus an accumulation of air in high latitudes, which will decrease the slope in the atmosphere. At the level of the soil the pressure increases towards the poles. We do not dwell further upon this type of circulation about which everyone seems to be agreed, and which has been well studied by Ferrel.

Effect of the Rotation of the Earth.

As, on the other hand, the earth turns upon its axis, the currents moving from the equator towards the poles will be deflected by a force dependent on the relative movement, and the gradients directed towards the pole will increase, until the slope of the isobaric surfaces is sufficient to overcome the component towards the equator due to centrifugal effects. For instance, in order to enable a West wind to keep a component towards the North, it is necessary that the slope of the isobars be greater than that of the surfaces of dynamic level which correspond to the relative velocity of this wind.

We must conclude from this, that in order to keep up the motion towards the pole, the slope of the surfaces of the upper isobars must be greater than those of the surfaces of dynamic level; and thus we see that the slope taken by the atmosphere in the higher regions does not depend only on the difference of temperature between the equatorial and the polar regions, as we have considered in the previous case.

It is to this different curvature of the upper isobaric surfaces, that is due the decrease of the pressure towards the poles, as Ferrel proved very clearly more than 30 years ago. But the calculation of the form of the isobars presents great difficulties as soon as one wishes to place oneself in actual existing conditions. Ferrel, by simplicity of reasoning, treats the problem on the hypothesis that friction has not any effect, and, in that case, it is possible to determine the isobars and the relative velocities, by the general equations of mechanics. Then he has reason as to the modifications which friction ought to introduce into this circulation, but without giving numerical equivalents as to the amount of friction and the modifications it would introduce.

Relative Velocity of the Winds and the Law of the Conservation of Areas.

The relative velocity of the rotation of the air, which displaces itself with relation to the earth, has often been, since Halley's time, considered as equal to the difference of velocity between the starting point of the air and its position at any given moment. According to that, it would be most near to the absolute velocity of equatorial rotation for an individual area coming from the equator to the pole. But Ferrel has shown, more than thirty years ago, that the principle of the conservation of areas was applicable (when there is no friction) to the relative movement of the air turning with a velocity different from that of the earth, so that the calculated velocity (either positive or negative) would be enormous, and would, at 60°, reach more than 2000 metres.

But if we calculate the slope of the isobars necessary to balance the north-south component of the centrifugal force for the velocities thus formed, we shall find that it corresponds to gradients vastly greater than those observed.

Ferrel has himself demonstrated that the polar depression would be such that there would be no more air at the poles, the whole atmosphere being thrown back on to the equatorial regions. He has, moreover, remarked that as friction greatly diminishes the velocities, the curvature of the isobars also would be much less.

But here we are obliged to consider an objection as to the lawfulness of applying the principle of the conservation of areas.

The law of the conservation of areas naturally depends on the principle of the conservation of energy. Now, for a mass of air turning round the earth, the actual velocity represents its actual energy; and the attraction exercised by the earth on this mass of air, is represented by the pressure which this mass of air exerts upon the horizontal plane, by reason of its potential energy.

The sum of these two energies ought to remain constant. Now, when we consider (as, in order to simplify matters, Ferrel did) the earth as a sphere, the distance to the centre of the earth from the air on the surface of the globe is thus constant, and the potential energy of a mass of air is then equal in high and in low latitudes, subject to the variation of gravity. As the kinetic energy increases in a very great proportion towards the poles, since the East winds there acquire, according to Ferrel, very considerable velocities, it is obvious that the mass considered has been under the influence of some accelerating force. This force must be sought in the gradient.

But this last, which results solely from the difference of temperature between the equatorial and the polar regions, is extremely weak as compared with the work which it has to do, and which could be computed. Hence it is impossible to attribute to this force the enormous increase of velocity which Ferrel's theory indicates for winds in high latitudes.

In fact, knowing the velocity of a body and the initial distance to the axis of rotation, one cannot deduce for another point the acceleration of motion from its distance to the centre, except on the hypothesis that there is there no loss of energy.

As soon as there is any friction, one has no right to conclude that since it was near its centre of rotation it has received some absolute acceleration; for it may approach this centre either when it is submitted to a central force of sufficient energy to overcome centrifugal effects, or when it is sufficiently retarded (by friction, or mixture with other masses) in its movement of rotation for its diminishing centrifugal force to be overcome by the central force.

As we do not know the magnitude of the effects of friction (mixtures of air, &c.), we cannot reasonably deduce the relative velocities of the air from its distance to the pole, nor say even whether the law of variation of velocity approaches that which could be deduced from the conservation of areas. But, on the other hand, it is necessary to endeavour to measure the known forces in order to deduce from them the velocities which they might impose upon air at different latitudes.

M. Möller, when criticising the employment by Ferrel of the formula of the conservation of areas, has indicated that there was one cause of the acceleration of the motion of the air (permitting thus, to a certain extent, the partial conservation of the moment of rotation) in the fact that the absolute horizon rises towards the poles by about 11,000 metres.

Without expressing a definite opinion on M. Möller's demonstration, I must remark that if we may thus attain considerable velocities of the air as mean values, we ought to find traces of them in the observed gradients. Now, these gradients in high latitudes are too small for trifling velocities towards the west.

However that may be, there is really towards the pole a lowering of the isobaric surfaces.

LOW BAROMETER AT THE EQUATOR, AREAS OF HIGH PRESSURE SITUATED ON THE EQUATOR.

This lowering, greater than could be produced by the contraction of the atmosphere consequent upon the difference of temperature alone, has many important effects upon the distribution of pressure above the surface.

(1) The height of the atmosphere goes on diminishing towards the pole, at the same time that the density of the air increases. Now, the pressure near the earth's surface depends especially on these two factors, and, neglecting some secondary effects of the vertical and horizontal movement, is near that which one might calculate by combining the products of the height of the atmosphere and its density. "It results therefrom that there ought to be a maximum somewhere between the pole and the equator." There cannot be a maximum at the pole, because the depression of the isobaric surfaces is greater than that which would result from the difference of temperature alone. It cannot be a maximum at the equator for two reasons: first the expansion of the air produces in places a flow which diminishes the mass of air over the equator; then, when this flow has been established, as it is fed in its lower part by the air (the trade winds) behind its daily motion, it results therefrom that the surfaces of dynamic level, for the upper current, are depressed from the equator up to a certain latitude where the velocities of the air and of the earth are identical.

Hence the isobars have a tendency to heap themselves up in equatorial regions, since the flow of the air can be maintained as soon as their curvature is less than that of the surfaces of dynamic level.*

But this influence, employed by Ferrel to explain the production of the equatorial minimum is not indispensable for that purpose, for the same would suffice for that as in the areas of low pressures, which are produced over continents consequent upon the influence of the heating of the soil. The decrease of pressure, slower in hot regions than in cold ones, produces a relative maximum of pressure above, hence the flow of air from one part to another, lowering of pressure by the departure of a certain mass of air, and establishment of a régime similar to that in a chimney above a burning fire. I will not dwell on this well-known and recognised fact, full details of which I have given in various memoirs, and among others in my "Etude sur la distribution relative des températures et des pressions moyennes à la Surface du Globe." *Ann. du Bureau Central Météorologique.* Tome IV., 1878. I will remark only that the equatorial minimum may be produced without the effects of relative motion coming into action.

Returning to the high pressure areas, we see that in each hemisphere the maximum is neither at the equator nor the pole but between the two.

In order to fix the position, Ferrel had recourse to two lines of argument:—1st. He said, This maximum divides the winds into two zones, the zone of East winds, and the zone of West winds; now, referring to the principle of the conservation of areas, *the sum of the moments, with reference to the axis of the earth, of the air which forms the East winds, ought to be equal to that of the air which forms the West winds;* now this condition is only filled for a hemisphere if East winds prevail up to 30°, and West winds thence to the pole.

This is true only if we may apply the principle of the conservation of areas, because then the relative velocity becomes a function of the distance to the centre of rotation, and its variation from one latitude to another is determined by a fixed law.

* The centrifugal gradient, or gradient resistant, is in fact a component directed towards the pole, although there is a retardation of the air; the effective gradient which sets the air in motion is then equal to the sum of the observed gradient with relation to a horizontal terrestrial surface, and of the centrifugal gradient, as I indicated at the Meteorological Congress in Paris, in 1889.

But in nature this principle, as we have said, is not applicable in a useful manner, for, the velocities admitted are reduced in variable and enormous proportions with the points of the globe; it results therefrom that the area occupied by East winds is not in a simple and mechanical relation with that occupied by the West winds.*

This is a very important fact, for it shows us that the areas of high pressure may be displaced (as we see in nature), so that there is not one type of invariable circulation, but there are several types, of which the Planets, by their multiple belts, give us examples. I will return later on to these bands and to their signification.

Ferrel has moreover recognised that the differences of velocity due to friction prevent the law which he enunciated being rigorous, and tend to place, in the Northern hemisphere, the limits of West and of East winds at about 30° instead of at 35°.

The reasoning is as follows:†

The velocities and distances to the axis of rotation of the earth ought to be such for East winds and for West winds, that one shall return to the earth that quantity of motion which the others have taken, for otherwise there would be a residual unexpended force in one direction or the other tending to change the velocity of the earth's rotation.

Now, this argument does not appear to us exact, when friction exists, for we seem to have there a loss of motion for the earth.

In fact, assume a West wind faster than the daily motion; this wind will tend to accelerate the earth's motion, and if it remains in contact with the earth it will finish by exhausting its relative velocity, but it exhausts its velocity in friction and not in employing all the movement it possesses in accelerating the earth, there is therefore conversion of a certain quantity of kinetic energy into heat.

In the second place, if this same mass of air be driven towards the equator by any local gradient, it will soon have a sensible retardation relative to the daily motion of the earth, now it tends by friction to take up the velocity of the earth's surface, there again there is a conversion of kinetic energy into heat and the entire quantity of motion lost by the earth is not given to the air but part of it is used in warming the air and the surface of the earth.

The final result of these two operations is, that the earth loses part of its motion by the displacement of the masses of air upon its surface. It does not fall within our duty to consider whether this effect could be detected by astronomers; moreover, there are other causes, such as the tides which tend to retard the earth's rotation; and there are others very small, but indisputable, which tend to accelerate it, such as the daily range of the barometer, as was shown some years since by Sir W. Thomson (Lord Kelvin). We therefore merely point out that the necessity for maintaining the velocity of the earth's rotation suggested by Halley and adopted by Ferrel, relying upon mechanics, ought to be left on one side, it being granted that friction exists and that it is accompanied by the conversion of motion into heat.

However, it may be admitted in a general way that the mass of the atmosphere is not behind, as compared with the daily movement. For that, since there is a transference of masses from the equator to the poles and *vice versa*, it is necessary that the surfaces on which the air rubs, either in exhausting its advance, or lessening its retardation, should be in a relation such that it may always

* The reduction in the velocity of the air may be due to friction against different surfaces where the friction is more or less intense, and the air, following the trajectory due to the local isobars, has a more or less prolonged contact with the earth's surface, a contact which tends to equalize the velocity of the air with that of the earth.

† *A popular treatise on the winds*, § 80.

take again the motion which it has lost by the air, when the latter has completed its course and returned to its original position.

But we see how much more elastic this principle is than those adopted by Ferrel, because it does not assume as fixed the law of the variation of velocities throughout a cycle, and it thus becomes applicable to very various types of the distribution of pressure. I will give later on the development of the consequences which may be deduced from this principle, it would take too long to explain them here.

We see then that the position in latitude of the pressure maxima cannot be fixed accurately because of the effects of friction, and in nature we see that this latitude varies much according to the season, since the mean distance which separates the maxima of pressure is about 75° in winter and 67° in summer, and that, according to the longitude, we may find in the same season the high barometer at 30° N. over the Atlantic, at 43° N. over the United States, and at more than 50° N. over nearly the whole of Asia.

If we consider the higher regions of the atmosphere we see these maxima approaching the equator, and at about 13,000 ft. they appear in winter to be actually on the equator, and in summer at about 20° N. Their position, then, seems defined: 1st, by the form of the surfaces of the upper isobars, which depends greatly upon the relative velocities of currents originating from differences of temperature over the globe, and such as exist with friction, and to the régime of the overflow from the anti-trades. 2nd, to the density of the air between the level of the upper isobars and the surface of the locality under consideration.

Relative Minimum of Pressure at the Latitude of 55°.

The study of the distribution of pressure shows that it falls very rapidly towards 50° latitude, has a minimum at about 55° N., and rises again towards the pole; or certainly the decrease of pressure is not continued.

This slight increase of pressure has already received the attention of meteorologists, and Dr. Sprung, setting out the theory of Ferrel who had not foreseen this increase, thought that it might be explained by the extraordinary lowness of the temperature of the lower atmosphere in the polar regions. But this explanation is not sufficient to account for that which occurs in summer.

On the contrary, if we consider the conditions of continuity of the atmospheric currents, we can explain how it is that the diminution of pressure towards the poles is arrested. The Westerly currents, starting from 40°, prevail both near the surface and up to many thousand mètres. These currents, in approaching the poles, have horizontal sections continually decreasing in consequence of the convergence of the meridians. Therefore, in order to maintain the same thickness, it is necessary that their velocity towards the pole should increase in the inverse ratio of the cosine of the latitude. But if one notices that, as a result of the effects of the deviatory force, their acceleration bears especially on their West-East movement, and that they tend to become, on the whole, almost parallel with the isobars (the cirri indicating already a tendency to return towards the equator) it results therefrom that the height of the currents tends to increase (or to diminish less rapidly, which is the same thing) towards the poles, and that thus the depression of the isobaric surfaces is less rapid; whence it results, as the density of the air increases, in producing a level surface, or even a slight increase of pressure.

This general effect, which gives an account of the distribution of pressure near the poles, is

slightly modified according to the longitude. First, when the maxima of lower pressure are found in a high northern latitude (as is the case over Asia and North America), the starting point of the lower winds which travel towards the poles is carried further North; whence it results that the horizontal breadth of these currents varies less than it does in those coming from latitudes nearer the equator; moreover, the velocity of these currents is much less than that of those over the ocean. It results therefrom that the effect of the horizontal contraction is felt only within much narrower limits, and that in these regions of the globe, the pressure continues to decrease towards the poles, as we see on the isobaric maps on a polar projection by Dr. Hann.

Over the oceans the variation of the temperature with latitude, which is the primary cause of movements towards the pole, is slow, and the winds are strong from the latitude of 45°, and do not increase as we approach the pole; the thickness of these currents must therefore increase more rapidly, and thus the lower pressure increases again towards the pole.

It will be noticed by this very fact that there is a tendency to an ascensional movement in the air. For if one speaks of a current which increases in thickness it is the same thing as saying that the filaments of it have a tendency to ascend. The ascending movements are, moreover, very predominant in the latitudes 50° to 60°.

Over the Atlantic and Pacific oceans, the effect of the marked thermic anomalies makes itself felt, and tends to keep the cyclones in position or to accentuate them; we have, to the South of Iceland and in the Alaska sea, very well marked zones of low pressure.

Upper Return Currents towards the Equator.

One point which still appears to us very obscure is the mode of formation of the return currents which bring back to, or towards, the equator, the air of the regions where the winds are directed towards the poles, both at the surface and at a certain height.

When a mass of air, about 55°, has risen into the upper regions in order that it may climb the slope of the isobars rising towards the middle latitudes (as is shown, for example, on maps 6 and 7 of pressures at 13,000 feet) it must have a considerable velocity towards the East, and greater than that of the winds which blow immediately under it. This march against the gradient is well explained by the deviatory force when the velocity is sufficient, but the general winds which rise in coming from districts near the surface have necessarily less velocities than the winds below them, and are thus deprived of the kinetic energy sufficient for contending against the upper gradient.

It seems to me to be absolutely necessary for this route to be possible to bring in the effect of barometric depressions, which give to the lower winds velocities much greater than those of the general winds which blow all around.*

As to the general westerly currents travelling towards the pole and returning to the equatorial regions, which Ferrel has placed in the highest strata of the atmosphere, it has not been possible to verify their existence, and I have long had doubts about them. Their mode of production is easily explained; it would be analogous to the mode of propulsion of the car of the "Montagnes Russes." The difference of temperature determines the slope of the isobars towards the pole; its trajectory modifies itself, the velocity acquired enabling it to regain the equatorial regions. But as it loses velocity through friction, it cannot accomplish a complete cycle, and can come back to the equator only at a less height than that whence it set out.

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* See "*Etude sur la Synthèse de la Répartition des Pressions à la Surface du Globe.*" *p. c.* 7.

But if, as Ferrel wished, we apply the law of conservation of areas to these currents, their existence becomes extremely difficult of comprehension. At great heights friction is very small, so that the velocities ought to approach the theoretical ones; from which it results that there must be a very considerable slope in order to overcome centrifugal effects.

Now, one finds oneself in this dilemma:—Either the elevation of the air necessary at the equator in order to produce this slope is due to a dynamic effect, and then the pressure at the equator ought to be very great in the lower regions, in consequence of the considerable mass of air which rises there; or the elevation is due to a difference of density, and then it is necessary that there should exist a difference of temperature between the equator and the pole which is not observed on the globe, or indeed that the currents should be produced at an enormous height.

M. Möller has, in fact, shown that it is necessary, in addition to the flattening of the globe, that the air should fall more than 21 kilometres in order to permit it to reach 60°. Now, the difference of temperature between the equator and the poles scarcely gives a fall of 900 metres at the height of 5,000 metres. It would therefore be necessary that the current directed towards the pole should be at an enormous height, in order that the effect of the equatorial heating should produce the necessary difference of elevation, which is that of at least 21 kilometres.

I leave these reflections for the consideration of meteorologists, and I think that my reservation as to these currents will be approved.

SUMMARY.

On the whole, it appears to me that the theory of circulation may be thus summarized:—

(1) Originally, the temperature is assumed to be constant, and the pressure uniform; the mass of the air is such that this pressure is about 760 millimetres.

(2) When the temperature of the globe ceased to depend on central heat, and began to be influenced by isolation, the difference of temperature between the pole and the equator was established, and increased, and gave rise to upper currents in the atmosphere, going from the tropics to high latitudes.

(3) By virtue of the relative movement of the air due to inertia, as Ferrel first showed, the winds going towards the poles tend to bend towards the East, and this tendency brings about the formation of a gradient towards the pole.

The surfaces of equal pressure thus draw closer to the earth as the latitude increases, and this they do in a greater proportion than would alone be done by the variation in the density of the air. This fact prevents the principal barometric maximum from being produced at the pole.

There are thus formed, in certain latitudes, barometric maxima where the product of the height of the air (included between the surface of equal pressure of the higher regions and the earth) by the density is at a maximum. These maxima are produced before reaching the polar regions, because there the surfaces of equal pressure are too low.

We find, then, between the equator and the high latitudes, a sort of horse-collar shaped mass of air, which is further increased by the retardation of the upper anti-trade and the effects of the relative movement of the lower air which forms the trade winds, and of the West winds of middle latitudes. This delay compels the isobaric surfaces to be somewhat depressed towards the equator, or rather, to be heaped up all around it.

(4) In high latitudes the convergence of the meridians, by diminishing the breadth of the currents, compels them to augment in height when their velocity does not increase rapidly enough, and this is usually the case; it results therefrom that the pressure passes by a minimum between the middle latitudes and the polar regions. This minimum has a variable latitude according to the intensity of the gradients which modify the increase in the velocity of the winds.

To this reason must be added the circulation of frequent barometric depressions, which are set in action by the anti-trades or great Western upper currents, depressions which move in a nearly circular zone in consequence of the regularity of the upper West winds, which are their principal source of energy.

These depressions necessarily bring about a notable decrease in the pressure throughout this zone; where this passage is rare, or where they do not stop long, we see the pressure decrease regularly towards the pole. For example, in Winter, in North America and Siberia.

(5) The differences of temperature which are produced over the globe between neighbouring regions, and especially in the same latitude between the continents and the seas, by changing the density of the lower strata of the atmosphere, destroy the regularity of the isobars, and bring about the formation of closed areas of high or of low pressure which break up the zones.

Thus are produced *the great centres of action of the atmosphere* which give to the general circulation its leading features.

Relatively to the position and to the number of the zones of high and of low pressure, the study of that which is going on upon certain planets seems to show that the question may be solved in many ways.

Moreover, we have seen that on our globe the position, the extent, and the intensity of the areas of high pressure, and the zones of low pressure, depend upon a complex mixture of causes which we have indicated, and of which many very important ones have been unknown or neglected by Ferrel, and subsequently by other mathematicians.

Synthesis of the Isobars: Construction of the Maps.

As we have already seen in determining by observation the mean value of barometric pressure in various latitudes and adding to the value thus found, the weight of the column of air which extends from the upper isobars to the surface, we thus obtain the elements necessary for tracing the maps Nos. 11 and 12. We have wished to go further and to calculate, according to theory, the mean form of the upper isobars.

The form of the upper surfaces of dynamic level depends, as we have seen, especially upon the relative velocities of the air. The isobars tend much to resemble these surfaces when the friction of the air is very small, as is the case in the upper regions. We can, ignoring the value of the effects of friction, admit that the isobars so closely approach the surfaces of dynamic level as to be identical therewith. We are thus certain of obtaining the minimum value of the gradient according to the meridian, since the slope of the isobars is at least equal to that of the surfaces of dynamic level.

In order to calculate the slope of the surfaces of dynamic level, we must know the relative velocity of the air in various latitudes. We have already seen that the law of the conservation of areas

leads to velocities much too great if we admit that the relative velocity should be equal (without the mixture of masses of air *en route*), to the difference of the velocity of the terrestrial parallels, that is to say, if we consider that the relative velocity depends upon inertia alone, we find for the gradients, values still much too large. Finally, if we admit that the true relative velocity is equal, for each latitude, to the square root of the theoretical velocity depending only on inertia, we obtain for the corresponding surfaces of dynamic level, values which closely approach those shown by the maps of the upper isobars deduced from observation, and these gradients, which can be computed, agree very well with the true ones.

Having once calculated the mean variation of pressure with latitude, it is necessary to see whether this variation is uniformly applicable to all meridians.

The study of the maps of the upper isobars shows us that the slope of the upper isobars is not the same on the different meridians, but that it appears steeper towards the regions where the difference of temperature with the equator is largest, which is, moreover, quite what was to be expected, because the thermal gradient is the real source of atmospheric movements.

To take account of this fact, we have multiplied by a coefficient which varies from 0 to 0·35 in January, and from 0 to 0·70 in July, the differences of pressure for a given distance, *i.e.*, the numerators of the gradients. The coefficients depend directly on the difference of temperature between the point considered and the mean for its latitude, being positive or negative, according as the temperature is in excess or defect.

As we see, this is to introduce directly the influence of the unequal distribution of temperature upon the form of the upper isobars.

This being settled, starting with the value of the pressure at the point where the upper isobaric surfaces begin to slope towards the pole, it is easy to determine the pressure in any given point by subtracting from this value the sum of the differences of pressure along the meridian, corrected for the effect of temperature. We have thus the pressure in the plane at 5,000 metres (16,000 feet) taken for our plane of investigation, it remains to add to this pressure the weight of the column of air extending from it to the earth's surface, a weight which we calculate by taking into account the temperature of the air at the place in question.

Thus we obtain the lower barometric pressures which have been transferred to maps and form maps 11 and 12 representing the computed mean isobars for January and July (second approximations).

We have just said that it is necessary to take for the point of departure that at which the isobars begin to slope towards the pole; really the point of departure ought to be the equator. It is difficult to fix the precise latitude at which the isobars begin to slope towards the pole, for we have seen that the maximum of barometric pressure is nearer to, or further from, the equator at different altitudes above the earth's surface.

According to our maps, at 4,000 metres (13,000 feet), the barometric minimum on the average appears to be at 15° or 20° on one side or the other of the equator. Judging from the velocity of transport of the Krakatoa dust towards the East, we may state that the retardation of the upper anti-trade is about 31 metres a second with regard to the daily motion; whence it would result that, without either loss or gain of movement, the air would find itself turning with the same velocity as the earth, at about 20°.

The surfaces of dynamic level are therefore sloping towards the equator up to about 20°, beyond which they slope towards the poles; but the swelling of the air at the equator tends to keep

the slope of the isobaric surfaces directed towards the poles. We have admitted that the range between the isobaric surfaces and those of dynamic level is 1·5 for the total distance between the the equator and 20°. As, moreover, the slope of the surfaces of dynamic level, computed according to the relative velocities, is very slight; if we diminish it by 1·5 we obtain an upper equatorial depression which is very slightly marked, and which agrees well with that which the maps of the upper pressures indicate.*

It was then easy, starting from the equator, to calculate the gradients along each meridian and to deduce therefrom the pressure for any given point. We have made this calculation only at each 5° along the meridians and for each 5° of longitude. When once these upper isobars had been obtained, the sea-level pressure could be computed by Laplace's formula, which we have done.

These values are represented on maps No. 11 and 12, which show close analogy with those representing the isobars deduced from direct observation. This proves that the principles on which my synthesis of the isobars rests, permits us to give an account of the distribution of pressure as regards its chief features.

We think that we ought to call the attention of meteorologists to this result.

REMARKS UPON THE ATMOSPHERIC CIRCULATION IN THE PLANETS.

We have seen that the distribution of pressure, and the circulation of the atmosphere, depend chiefly upon the difference of the temperature at the equator from that at the poles, and on the effects of relative movement of which the magnitude depends upon the centrifugal force due to the rotation of the globe.

These various factors have different values upon the several members of our Solar system. Therefore on the individual planets (while obeying the same general laws, which are those of mechanics) the circulation of their atmospheres ought to present types of atmospheric circulation differing more or less from that prevalent upon our globe.

It will therefore be very interesting to complete our theory of the circulation of the atmosphere, and to ascertain the changes brought about by variations in the several factors, by studying the general circulation in the atmosphere of the planets. Unfortunately we cannot do this thoroughly, but in the absence of data as to the pressure and wind currents, we can indirectly deduce from their aspect, their elements, diameter, mass, velocity of rotation, and from the composition of their atmosphere, some valuable generalities as to their meteorology.

My researches upon the laws of the distribution of cloud over the surface of the globe, furnish one valuable means of ascertaining the broad features of the distribution of barometric pressure

* I ought to mention here an apparent anomaly in the motion of the upper currents in summer over India and Southern Asia. Although in the theoretical circulation we assume that the point of convergence of the winds is at the equator, over the continents and especially in Asia, the heat of the soil is so great in summer that the point of convergence of the wind is shifted to about 25° N. But this effect is confined to the lower strata, and between the equator and the zone of low pressure, there is no anti-trade, as would have been expected from what occurs near the earth's surface. Hence it results that the upper winds blow from the west with a slight northerly component, as M. Hildebrandsson has been able to prove from observations of cirri.

I have moreover shown in my memoir on the synthesis of pressures before this fact was proved by observation, that the gradients of the upper strata of the atmosphere in the region included between the equator and Asia ought not to be computed by assuming that the air lags behind the daily motion, and that beyond the region of the convergence of the monsoon the upper winds blow from S.S.W. to W. This is because the air which feeds the monsoon on its passage towards the N. finishes by having an excess of velocity over the diurnal rotation.

If we calculate the upper gradients, assuming as for the anti-trades that the slope of the surfaces of level is directed towards the equator, we shall obtain for the lower isobars pressures increasing much too rapidly towards the N.

It is very satisfactory to remember that in this case theoretical considerations led us to announce this apparent anomaly before observation had indicated it.

on a planet according to the disposition of the bands, which in all probability are produced by the contrast in the light from those portions of the body of the planet covered by, and those free from, cloud.

In fact, the study of maps of isonephs (equal amounts of cloud) compared with those of other meteorological elements, shows that the cloudiness depends chiefly on the vertical component of the air. It is indeed evident that a mass of air which rises in consequence of the arrangement of surfaces of equal pressure in the atmosphere by the cooling due to expansion, reaches a temperature low enough to condense the vapour contained in it. It follows that above regions where there are frequently low pressures, the cloudiness should be great, and on the contrary above regions where there are high pressures and therefore descending currents, a clear sky should prevail; as indeed is known to be the case.

As we have already pointed out, the high and the low pressures and the wind systems are frequently arranged in zones or belts, whence it is probable that the distribution of cloud will be similar. In fact it has been found that—

(1) In every month there is a well-marked tendency for the cloudiness to arrange itself in zones parallel to the equator.

(2) When the distribution of cloudiness is separated from the perturbations which complicate it, so that the general phenomena can alone be considered, there are seen to exist—

(*a*) A maximum of cloud at the equator, changing its position slightly with the sun's declination, and in fact agreeing with the belt of low pressure.

(*b*) A band of little cloud between 15° and 35° both N. and S., corresponding to the high pressure region.

(*c*) A zone of clouded sky from 40° to 60° above the regions of barometric depressions,

(*d*) While in higher latitudes, judging by what occurs in the northern hemisphere, the sky becomes clearer towards the poles.

Now we see that the distribution of the cloudiness is, as a whole, a direct consequence of the variation of the wind and especially of the direction of its vertical component, and also of the humidity, although this last only plays a ruling part in the extremes. The winds themselves depend upon the distribution of pressure which is thus the preponderating influence.

These same phenomena occur in their essential features on the planets which possess an atmosphere, and the bands of clear or cloudy sky which exist on the earth ought to correspond to bands of the same kind which are obverved on different planets. Seen from a point in space the cloud bands of the earth would appear brilliant, while the regions where the slightly clouded sky permits the soil to be seen would be darker, this aspect being well known to persons who have ascended on mountains or in balloons. If, accordingly, we picture our globe as seen in space, by representing the cloudiness by tints darker in proportion as the earth's surface is more visible, we obtain something like Figures 13 and 14. In order to render the analogy with the other planets more striking, we give in Figure 15 the aspect of Jupiter with his bands on April 21, 1886, from the photographs of MM. Henry of the Paris Observatory.

One can see in these photographs, as in most of the later ones taken with the greatest care by M. Trouvelot of the Meudon Observatory, and by M. Boinot of the Paris Observatory, that there exist upon Jupiter two darker bands near latitude 15° and three light bands, one at the equator, the others near the tropics. On Saturn, direct observations show, as do the photographs, similar bands. Upon Mars no bands have been found, but from time to time the planet appears

surrounded by clouds which prevent its surface from being distinctly seen. But then the researches of astronomers have been rather upon the configuration of the surface of this planet, and not on the arrangement and amount of the clouds which appear there; this has been noted only when the planet was most visible, so that the circumstances regulating the clouds on Mars are unknown. There are, moreover, probabilities based upon scientific reasons, that the clouds upon Mars are not distributed in the same manner as upon the earth.

On Jupiter the centrifugal effects are much greater than upon the earth, and therefore the effects of relative movement are much more marked, and the surfaces of dynamic level in the air ought to be much more inclined towards the poles, whence it results that the high pressure zones ought to be nearer the equator. Observations show that this is the case and that the dark bands corresponding to clear sky are found at about 15° on each side of the equator.

Moreover, as on account of the rapid rotation of this planet, the atmospheric movements which tend to be meridional are changed into motions nearly along parallels of latitude, series of narrow bands are often seen extending beyond middle latitudes.

On the earth, on the contrary, there are at the most only seven bands, three light and four dark; the light ones (overcast sky) at the equator and at about 50° N. and S., and the dark ones (clear sky) about 30° N. and S., and in the polar regions.

Thus the distribution of clouds (taking the word in its broadest sense as covering clouds resulting from the condensation of liquid vapour, be the liquid on the planets what it may) furnishes us with the means of studying at a distance the distribution of barometric pressure, and the laws of the winds in the atmospheres of the planets.

It seems to me desirable to call the attention of astronomers to these new ideas, which will add to the interest attaching to photographs of the planets, and, as soon as sufficient data have been collected, I hope much from further study of general meteorology now that it has been extended to the planets.*

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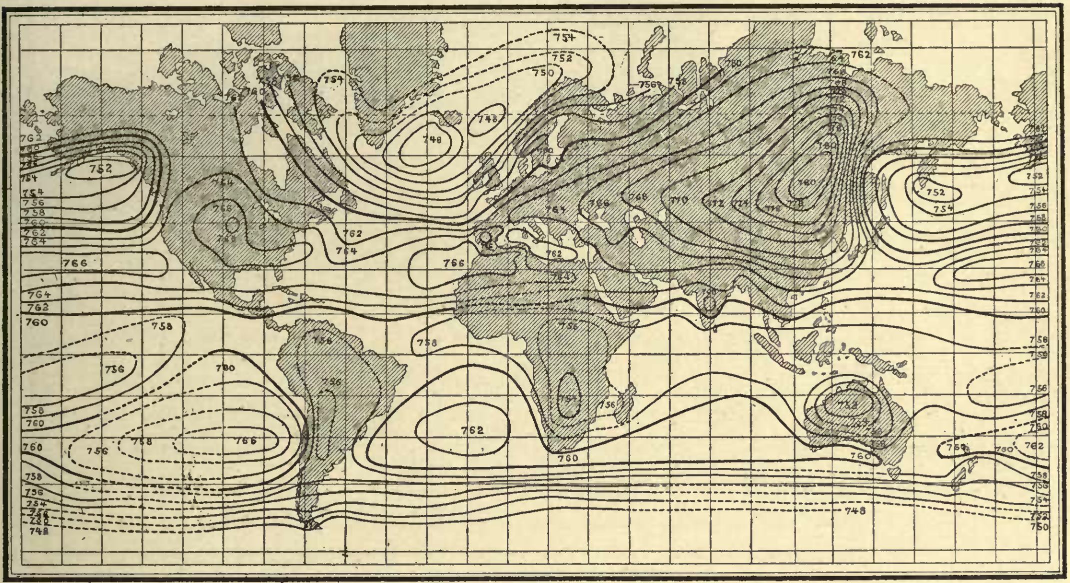
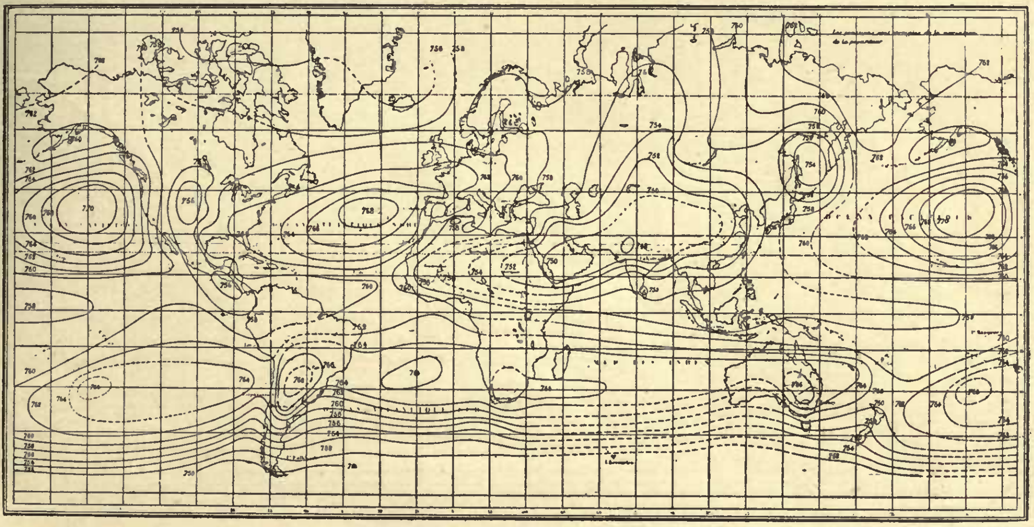
* The writer would be very grateful to persons who will be good enough to send photographs of the planets, or drawings made at different phases, to him at 82, Avenue Marceau, Paris.

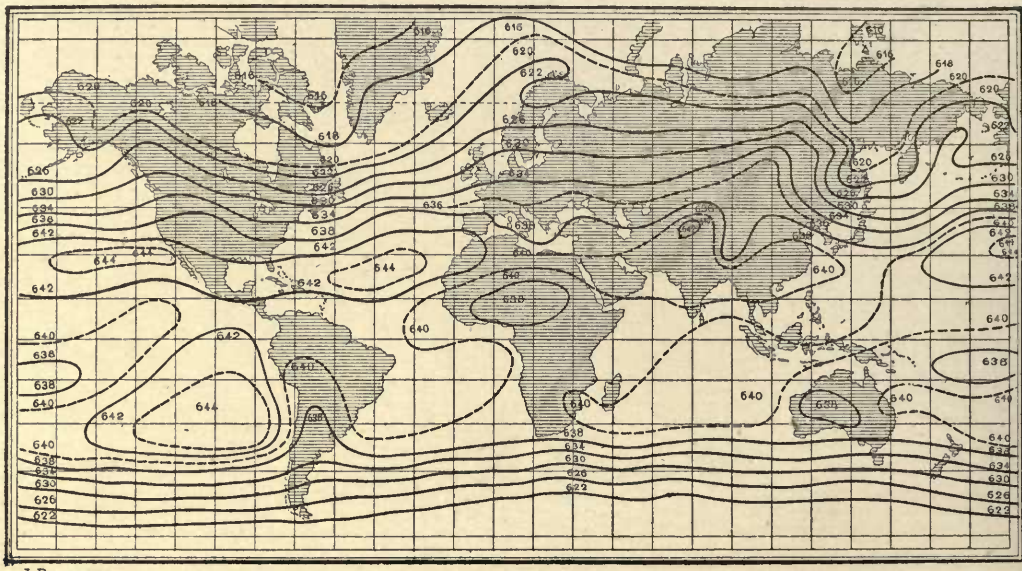
No. 1.—Mean Isobars for January (observed).



No. 2.—Mean Isobars for July (observed).

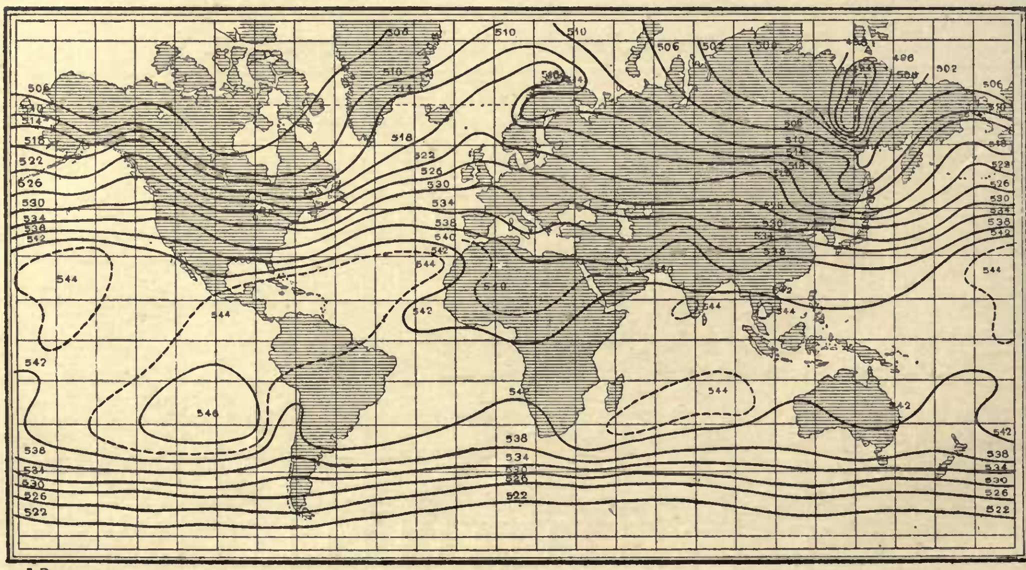


No. 3.—Mean Isobars for January, at 1,467 m. (4,813 ft.)



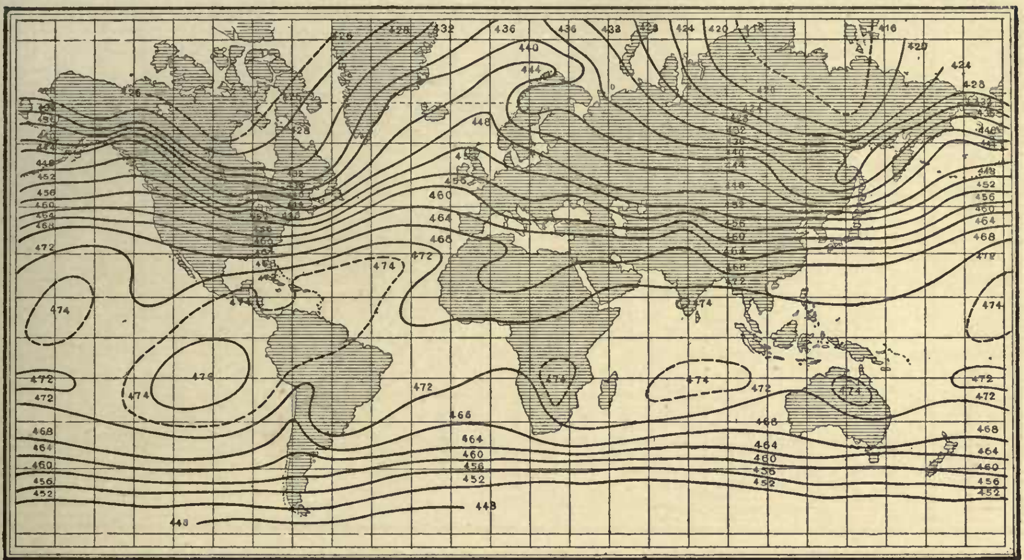
J Blanadet

No. 4.—Mean Isobars for January, at 2,859 m. (9,186 ft.)



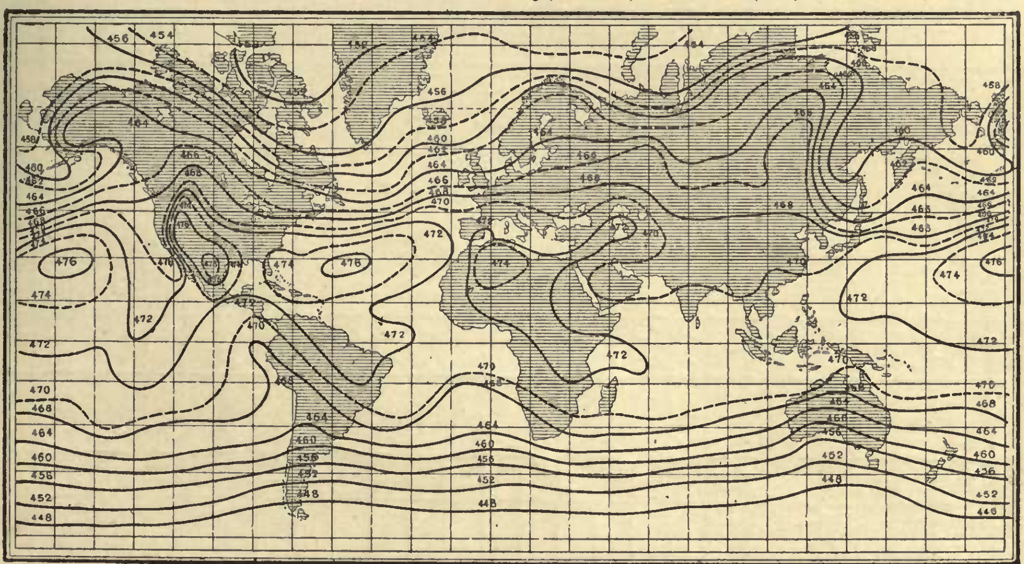
J Blanadet

No. 5.—Mean Isobars for January, at 4,000 m. (13,000 feet).



J. BLANADET

No. 6.—Mean Isobars for July, at 4,000 m. (13,000 feet).



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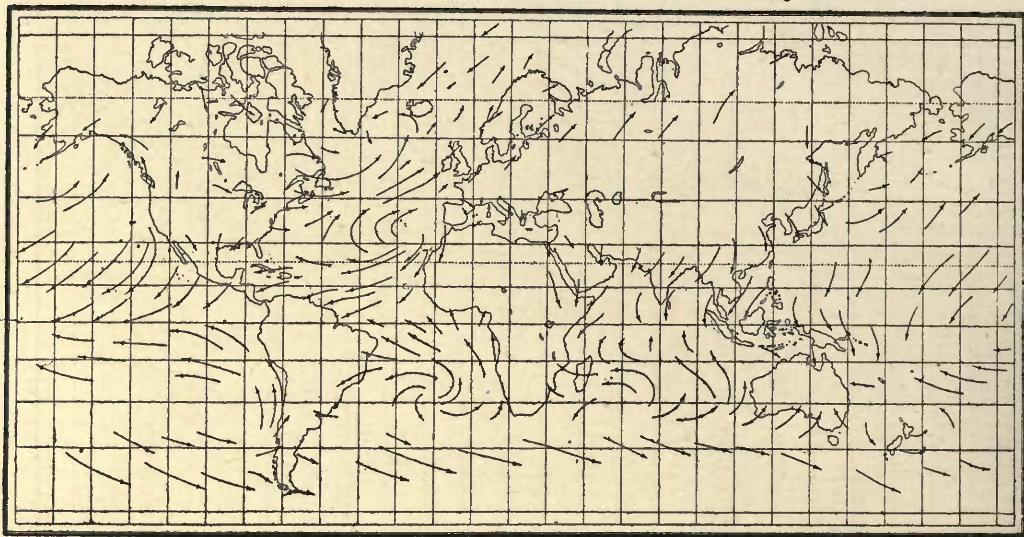
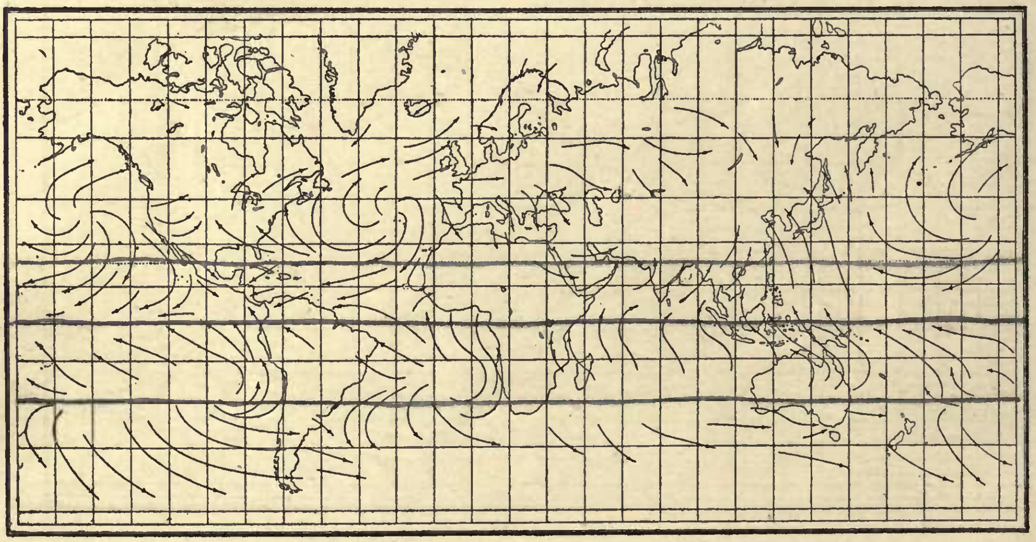
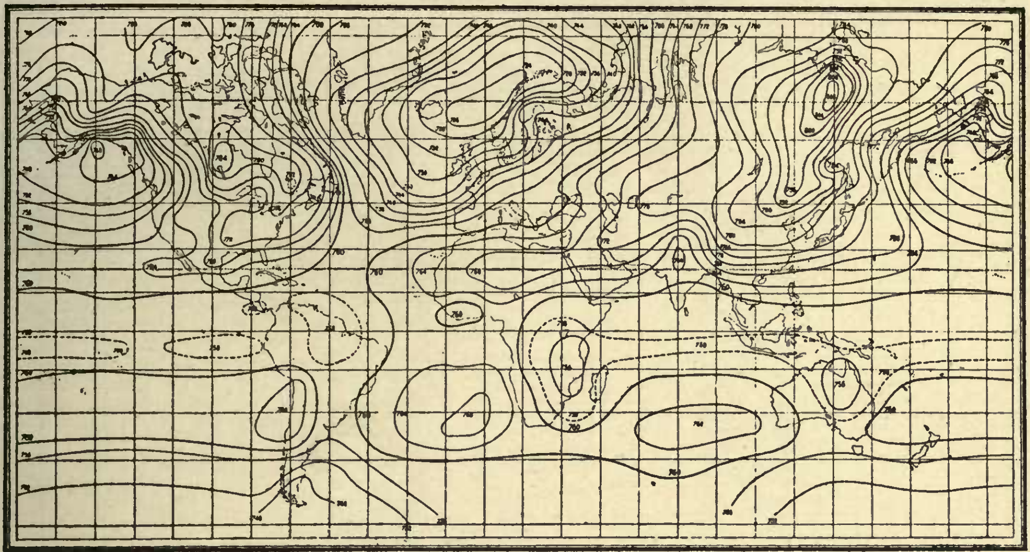
No. 7.—Prevailing Winds in January.



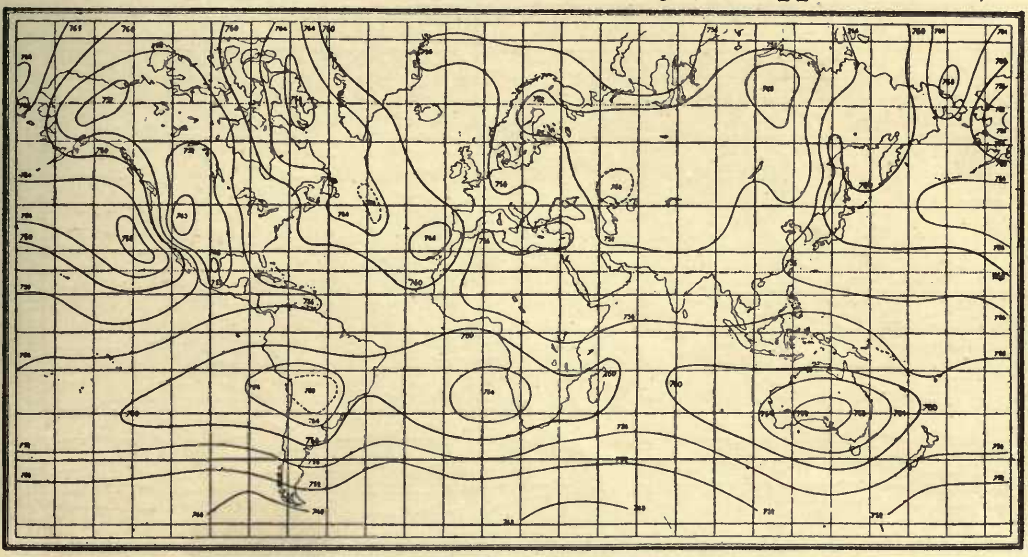
No. 8.—Prevailing Winds in July.



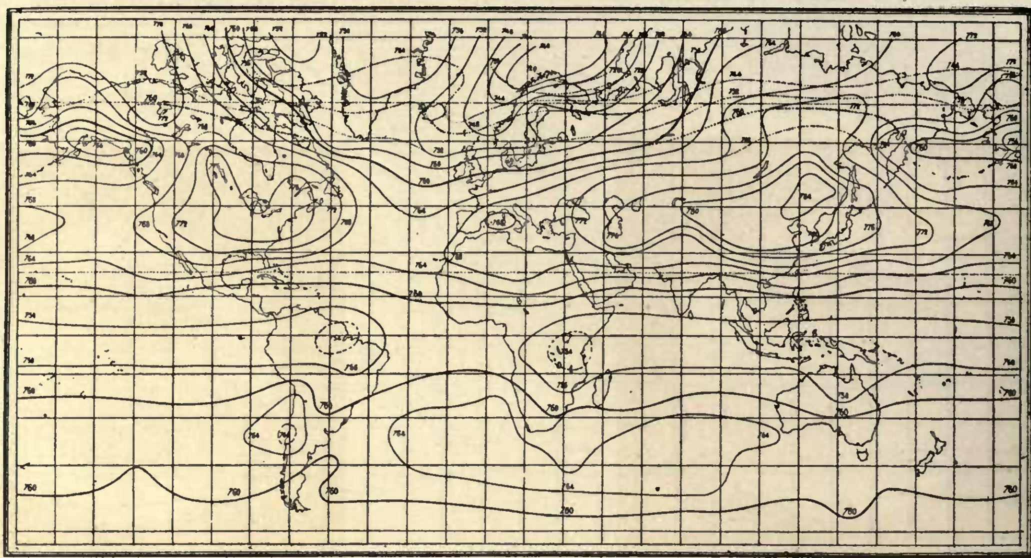
No. 9.—Computed Mean Isobars for January (1st Approximation).



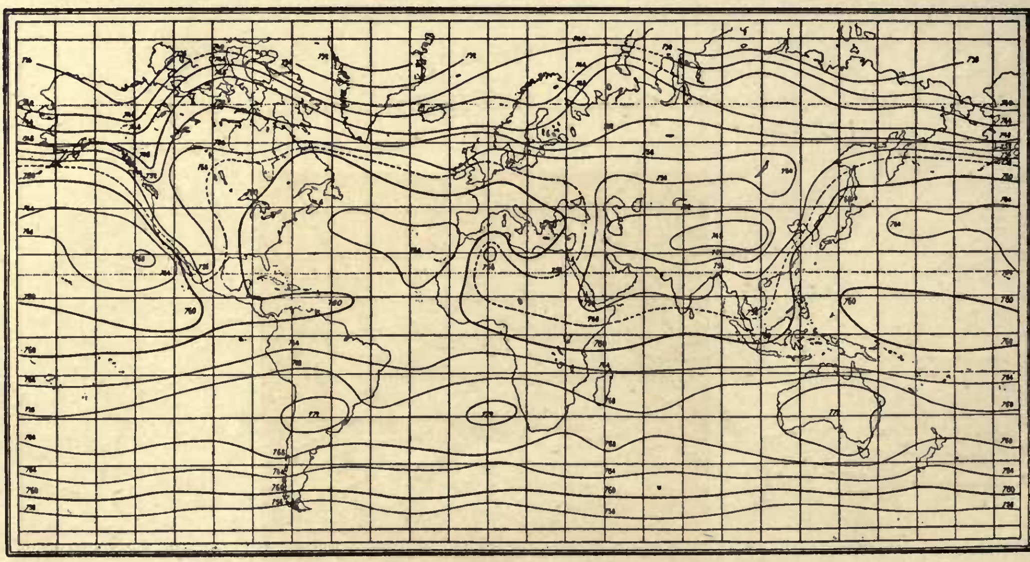
No. 10.—Computed Mean Isobars for July (1st Approximation).



No. 11.—Computed Mean Isobars for January (2nd Approximation.)



No. 12.—Computed Mean Isobars for July (2nd Approximation).

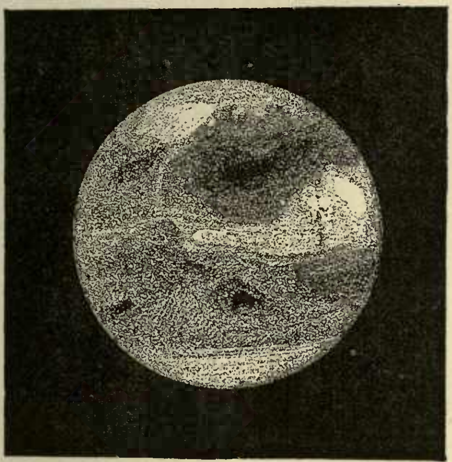


THE EARTH

(as seen from Space in July with its covering of cloud).

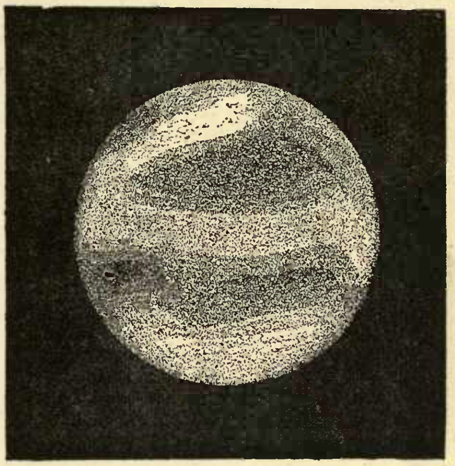
No. 13.

The old Continent—Europe & Asia.



No. 14.

The Pacific Ocean.



JUPITER

(as seen from the Earth with its cloud bands).

No. 15.

From a photograph taken by MM. Henry at the Paris Observatory, April 21st, 1886.